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(54) Improvements in drilling equipment.

(57) A drill string for drilling deep wells is provided with a device (16) for providing a pulsating flow of the pressurized drilling fluid to the jets of the drill bit (20) to enhance chip removal and provide a vibrating action in the drill bit (20) itself thereby to provide a more efficient and effective drilling operation. The device (16) includes a rotating valve (56) on a rotor (36) driven by turbines (52) rotated with respect to a stator (34) by the drilling fluid as it passes through the device (16) on its way to the drill bit (20). The pressure pulses thus generated rise to peaks in excess of the mean pump pressure without requiring an increased pumping capacity.

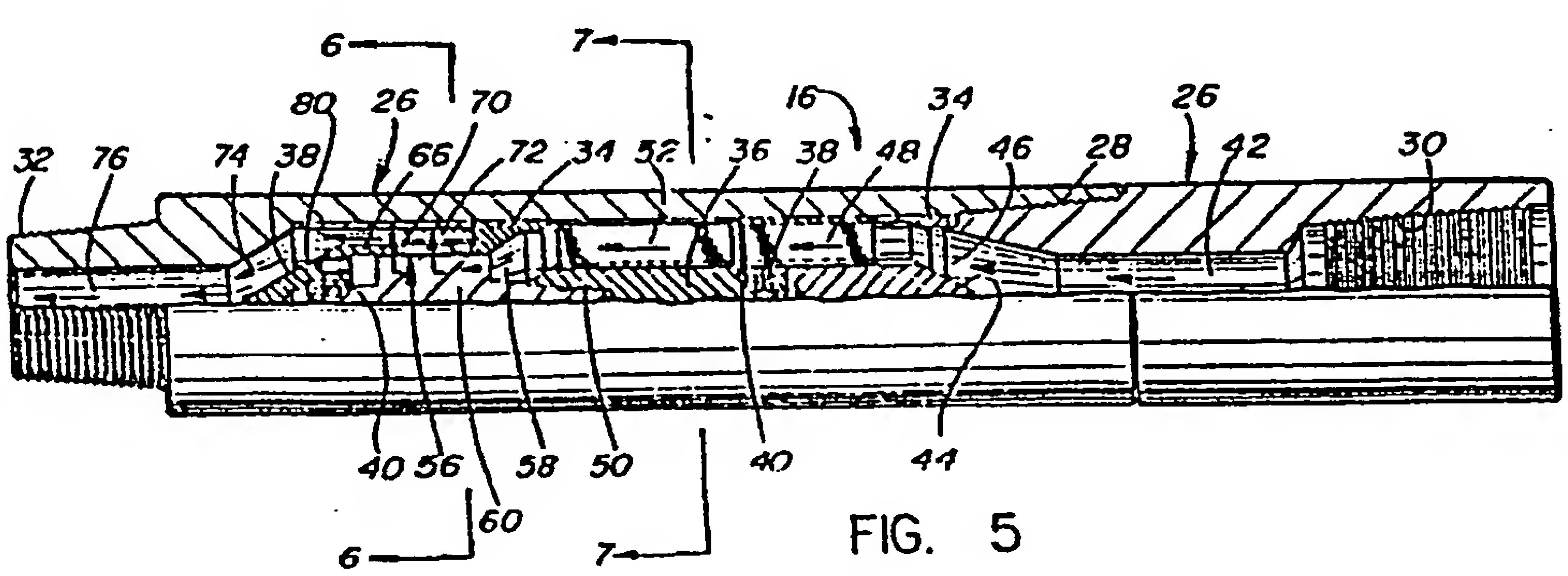

FIG. 5

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IMPROVEMENTS IN DRILLING EQUIPMENT

In the drilling of deep wells such as oil and gas wells, it is common practice to drill utilizing the rotary drilling method. A suitably constructed derrick suspends the block and hook arrangement, together with a swivel, drill pipe, drill collars, other suitable drilling tools, for example reamers, shock tools, etc., with a drill bit being located at the extreme bottom end of this assembly which is commonly called the drill string.

The drill string is rotated from the surface by the kelly which is rotated by a rotary table. During the course of the drilling operation, drilling fluid, often called drilling mud, is pumped downwardly through the hollow drill string. This drilling mud is pumped by relatively large capacity mud pumps. At the drill bit this mud cleans the rolling cones of the drill bit, removes or clears away the rock chips from the cutting surface and lifts and carries such rock chips upwardly along the well bore to the surface.

In more recent years, around 1948, the openings in the drill bit allowing escape of drilling mud were equipped with jets to provide a high velocity fluid flow near the bit. The result of this was that the penetration rate or effectiveness of the drilling increased dramatically. As a result of this almost all drill bits presently used are equipped with jets thereby to take advantage of this increased efficiency. It is worthwhile to note that between 45-65% of all hydraulic power output from the mud pump is being used to accelerate the drilling fluid or mud in the drill bit jet with this high velocity flow energy ultimately being partially converted to

pressure energy with the chips being lifted upwardly from the bottom of the hole and carried to the surface as previously described.

As is well known in the art, a rock bit drills by forming successive small craters in the rock face as it is contacted by the individual bit teeth. Once the bit tooth has formed a crater, the next problem is the removal of the chips from the crater. As is well known in the the art, depending upon the type of formation being drilled, and the shape of the crater thus produced, certain crater types require, much more assistance from the drilling fluid to effect proper chip removal than do other types of craters. For a further discussion of this see "Full Scale Laboratory Drilling Tests" by Terra-Tek Inc., performed under contract Ey-76c-024098 for the U.S. Department of Energy.

The effect of drill bit weight on penetration rate is also well known. If adequate cleaning of the rock chips from the rock face is effected, doubling of the bit weight will double the penetration rate, i.e. the penetration rate will be directly proportional to the bit weight. However, if inadequate cleaning takes place, further increases in bit weight will not cause corresponding increases in drilling rate owing to the fact that formation chips which are not cleared away are being reground thus wasting energy. If this situation occurs, one solution is to increase the pressure of the drilling fluid thereby hopefully to clear away the formation chips in which event a further increase in bit weight

will cause a corresponding increase in drilling rate. Again, at this increased drilling rate, a situation can again be reached wherein inadequate cleaning is taking place at the rock face and further increases in bit weight will not significantly affect the drilling rate and, again, the only solution here is to again increase the drilling fluid pumping pressure thereby hopefully to properly clear the formation chips from the rock face to avoid regrinding of same. Those skilled in the art will appreciate that bit weight and drilling fluid pressure must be increased in conjunction with one another. An increase in drilling fluid pressure will not, in itself, usually effect any change in drilling rate in harder formations; fluid pressure and drill bit weight must be varied in conjunction with one another to achieve the most efficient result. For a further discussion of the effect of rotary drilling hydraulics on penetration rate, reference may be had to standard texts on the subject.

It should also be noted that in softer formations, the bit weight that can be used effectively is limited by the amount of fluid cleaning available below the bit. In very soft formations the hydraulic action of the drilling fluid may do a significant amount of the removal work.

In an effort to increase the drilling rate, the prior art has provided vibrating devices known as mud hammers which cause a striker hammer to repeatedly apply sharp blows to an anvil, which sharp blows are transmitted through the drill bit to the teeth of the rolling cones. This has been found to increase the drilling rate significantly; the disadvantage however is that the bit life is

significantly reduced. In a deep well, it is well known that it takes a considerable length of time to remove and replace a worn out bit and hence in using this type of conventional mud hammer equipment the increased drilling rate made possible is offset to a significant degree by the reduction in bit life.

The present invention seeks generally to provide improved means for increasing drill bit penetration rate such as by providing improved chip removal from a bore hole. The invention also seeks to provide relatively simple and economical equipment in which a pulsating flow of the pressurized drilling fluid is supplied to the jets of the drill bit, which equipment is also capable of providing a vibrating action in the drill bit itself. A faster penetration rate can thus be achieved in both hard and softer formations thereby greatly improving the economics of the drilling operation without, at the same time, requiring additional expenditures in terms of drilling fluid pumping capacities or pressures.

According to one aspect of the present invention, there is provided apparatus for providing a pulsating flow of drilling fluid to a rotary drill bit characterised in that it comprises a housing adapted to be connected in a tubular drill string above the drill bit and to be supplied, in use, with pressurized drilling fluid via the tubular drill string, said housing having a passageway for the flow of the drilling fluid therethrough from an inlet to an outlet of the housing, and pressure varying means in the housing for cyclically varying the rate of

flow of drilling fluid through the housing to create a varying pressure in the drilling fluid leaving the outlet from the housing whereby, in use, a pressurized pulsating flow of such fluid is supplied to the drill bit.

In another aspect the invention provides drilling equipment including a rotatable hollow drill string adapted to carry pressurized drilling mud downwardly into a well bore, and a drill bit connected to the lower end of the drill string, characterised in that there are provided means in the said drill string above the said drill bit adapted to be activated by the flow of drilling mud whereby periodically to interrupt a portion of the flow of drilling mud so as to set up a water hammer effect therein so that pulsating forces are applied to the drill bit which is supplied with a flow of the drilling mud at a pulsating pressure, the said drill bit having a nozzle means thereon to direct the pulsating pressure flow to regions of the bottom end of the well bore during use to clear away cuttings produced by the drill bit.

The present invention also comprehends a method of drilling a bore hole including rotating within a bore hole a hollow drill string to the lower end of which a drill bit is connected, such drill bit having nozzle means therein for directing drilling mud supplied thereto via said drill string to the bottom of the bore hole to clear away cuttings produced by said bit and/or to assist in the cutting of softer formations, characterised in that a portion of the flow of drilling mud through said drill

string is interrupted in a cyclical fashion so that said drill bit is supplied with a pulsating pressurized flow of the drilling mud.

The primary function of this apparatus of the invention is to cause the drilling fluid to pulse and this pressurized pulsing action creates additional turbulence at the bottom of the hole, as compared to the prior art arrangements, thus resulting in better removal of material from the bottom of the bore hole. This pulsing action also is capable of providing a vibrating or percussive action on the drill bit, both of which effects result in significant improvement in penetration rate.

In a preferred form of the invention, the apparatus includes an external housing adapted to be connected in a tubular drill string above a drill bit and to be supplied, in use, with pressurized drilling fluid via the drill string. Suitable means are provided within such housing for cyclically varying the flow of drilling fluid through the housing from the inlet to the outlet end of same thereby to create a fluctuating or pulsating pressure in the drilling fluid.

In use, this pulsating flow of pressurized fluid is made available to the jets of the drill bit. Additionally, the cyclical flow variations, by virtue of the acceleration and deceleration of the column of drilling fluid within the drill string, serve to apply pulsating mechanical forces to the drill bit.

In a typical embodiment of the invention the above-noted housing includes a rotor having blades which is adapted to rotate in response to the flow of drilling fluid through the housing. Rotary valve means are connected to the rotor for alternately closing and opening these passages thereby to create the cyclical pressure fluctuations.

In one embodiment of the invention, the rotary valve means includes a member which alternately closes and opens relatively large fluid ports within the housing thus decreasing and increasing the flow of drilling fluid. At the same time small fluid ports are continually open thereby to provide a continuous flow of fluid through the ——————————

apparatus. When the main large ports are closed by the rotary valve, the pressure of the drilling fluid entering the apparatus rapidly increases while the pressure of the drilling fluid supplied to the drill bit jets rapidly decreases. Opening of the main large ports by the rotary valve allows this accumulated pressure to pass freely through the apparatus and to surge with increased velocity out of the drill bit jets. This pulsing action increases the turbulence at the hole bottom or rock face and enhances the hydraulic cleaning power of the drilling fluid. At the same time this pulsing hydraulic pressure creates a pulsing mechanical force on the drill bit which further enhances the drilling rate.

In a further form of the invention the above-described apparatus can be attached to a form of shock tool which responds to the pulsating fluid pressure by expanding and contracting so that, in effect, it functions similar to a mud hammer. However, since the force is applied hydraulically with no extremely sharp pressure peaks, the bit life is not adversely affected to any significant degree.

The pulsating action enables one to take advantage of the inertia effects of the long column of drilling fluid standing in the drill string and hence the peak pressure made available to the drill bit jets can be made at least double that available utilizing conventional techniques. At the same time it should be realized that this substantially increased bit jet pressure does not require the use of additional high volume high pressure pumping equipment thus keeping both equipment and operating costs at reasonable levels.

Preferred embodiments of the invention will be described hereafter. It will be seen that this novel apparatus permits a substantial number of variables to be altered at will. For example, both the frequency and amplitude of the fluid pressure pulses can be preselected in accordance with requirements. In the case where the equipment is combined with a form of shock tool, the amplitude of the mechanical force can be suitably regulated by varying either the pressure or the areas of the shock tool which are exposed to the fluctuating hydraulic pressures.

Various embodiments of the invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 is a graph illustrating the relationship between drilling rate and bit weight and illustrating the effect that increased cleaning or better chip removal has on drilling rate;

Figure 2 is a longitudinal section at the bottom of a well bore illustrating apparatus according to the invention connected in the drill string immediately above the drill bit;

Figure 3 is a view similar to that of Figure 2 but additionally incorporating a form of shock tool located immediately below the means for producing the fluctuating flow of drilling fluid;

Figure 4 is a diagrammatic view of the bottom end of a bore hole illustrating a jet of drilling fluid emitted toward the wall and bottom of a bore hole;

Figure 5 is a longitudinal half section of apparatus

for producing a pulsating or fluctuating flow of drilling fluid in accordance with the invention;

Figure 6 is a cross section view taken along line 6-6- of Figure 5;

Figure 7 is a cross section view taken along line 7-7 of Figure 5;

Figure 8 is a diagrammatic view illustrating the relative sizes of the main ports and the continually open ports and leakage areas provided by the valving means of the apparatus shown in Figures 5 to 7;

Figure 9 is a graph illustrating the bit-jet pressure as a function of the angular position of the rotor;

Figure 10 is a longitudinal half section of a modified form of apparatus for producing a fluctuating flow of drilling fluid;

Figures 11 and 12 are cross section views taken along lines 11-11 and 12-12 of Figure 10 respectively;

Figure 13 is an exploded view of apparatus in accordance with the present invention incorporating, in addition, a shock tool which is interposed between the drill bit and the apparatus for producing the fluctuating flow of drilling fluid; and

Figure 14 is a graph illustrating the loadings on the drill bit resulting from the use of the apparatus illustrated in Figure 13.

Reference will be had firstly to Figure 1. As noted previously the effect of bit weight on penetration rate is well known. With adequate cleaning, penetration rate is directly proportional

to bit weight. There are some limitations depending of course upon the type of formation being drilled. There is also, in any particular situation, a maximum upper limit to the magnitude of the weight which the bit can withstand.

With reference to Fig. 1, it will be seen that drilling rate is generally proportional to bit weight up to point A where drilling rate drops off rapidly owing to inadequate cleaning which means that formation chips are being reground. From point A, increased cleaning resulted in a proportional increase in drilling rate up to point B where, again, inadequate cleaning was in evidence with a consequent fall off in drilling rate. Again, by increasing the cleaning effect, drilling rate once again became proportional to bit weight up to point C where again, a fall off in drilling rate is in evidence.

Fig. 1 thus demonstrates clearly the importance of effective hole bottom cleaning in obtaining an adequate drilling rate.

It is noted that Fig. 1 has been described mainly in relation to the drilling of harder formations. In softer formations, where the hydraulic action of the drilling fluid does at least part of the work, the relationships shown in Fig. 1 would still apply, although for somewhat different reasons, as those skilled in the art will appreciate.

Referring now to Figure 2, there is shown in cross section the lower end portion of a bore hole within which the lower end of a drill string 10 is disposed, such drill string including sections of hollow drill pipe connected together in the usual fashion and adapted to carry drilling fluid downwardly from drill pumps (not shown) located at

the surface. The drill string is driven in rotation by the usual surface mounted equipment also not shown. Attached to the lower end of the drill collar 12 via the usual tapered screw thread arrangement is a drilling fluid flow varying or pulsing apparatus 16 in accordance with the invention. To the lower end of the flow pulsing apparatus is connected a relatively short connecting sub 18 which, in turn, is connected via the usual screw threads to a drill bit 20 of conventional design having the usual rolling cone cutters and being equipped with a plurality of cleaning jets suitably positioned to apply streams of drilling fluid on to those regions where they have been found to be most effective in removing chips from the bottom of the well bore. One of such cleaning jets 22 is diagrammatically illustrated in Fig. 4 (the remainder of the drill bit not being shown) thereby to illustrate the manner in which the jet of drilling fluid is directed against the side and bottom portions of the well bore during a drilling operation. The location and arrangement of the jet openings on the drill bit 20 need not be described further since they are not, in themselves, a part of the present invention but may be constructed and arranged in an entire conventional manner.

Fig. 3 is a view very similar to that of Fig. 2 and like components have been identified with the same reference numbers as have been used in Fig. 2. However, it will be seen from Fig. 3 that, interposed between the flow pulsing apparatus 16, and the lower connecting sub 18, is a shock tool 24. As will be described in further detail hereafter, this shock tool is arranged to respond to the fluctuating

or pulsing fluid flow being emitted from flow pulsing apparatus 16 thereby to cause vibration or oscillation of the drill bit 20 in the direction of the drill string axis thereby to further enhance the efficiency of the drilling operation.

Referring now to Figs. 5, 6 and 7, the flow pulsing apparatus 16 is shown in detail. Apparatus 16 includes an external tubular housing 26, the wall of which is sufficiently thick as to withstand the torsional and axial forces applied thereto during the course of the drilling operation. Housing 26 is in two sections which are connected together via tapered screw threaded portion 28, with the upper end of the housing having a tapered internally threaded inlet 30 adapted for connection to a lower end portion of the drill string. The housing 26 also includes a tapered externally threaded outlet 32 adapted to be screwed into the connecting sub 18 which in turn is connected to drill bit 20 as illustrated in Fig. 2 or, alternatively, threaded into the upper end of the shock tool 24 illustrated in Fig. 3.

Housing 26 contains therein an elongated stator portion 34 within which an elongated rotor 36 is journaled via ball bearing assemblies 38 located at the upstream and downstream end of the rotor. It will be noted that ball bearing assemblies 38 are arranged as thrust bearings thereby to effectively take up axial loadings applied in use to rotor 36. Annular seals 40 located in suitable annular grooves in the rotor help to prevent entry of contaminants into bearings 38.

The housing 26 has, adjacent the upstream end thereof, a central bore 42 defining a passageway for the flow of drilling fluid into the interior of

the housing. The upstream end of stator 34 includes a flow diverting portion 44 which diverts the flow into a generally annular region 46, such annular region including a plurality of radially arranged straight stator blades 48, each such stator blade 48 lying in a plane which intersects the longitudinal axis of housing 26. The stator blades 48 extend from the central or hub portion of the stator outwardly to the inner periphery of the stator and the same are securely connected to the stator as by welding. The purpose of the straight stator blades is to prevent creation of a rotating vortex which would tend to reduce the efficiency of the fluid turbine to be hereafter described. In a typical embodiment, the stator may include about eight such blades 48 equally angularly spaced apart around the axis of the housing 26.

The rotor 36 is positioned immediately downstream of stator blades 48, such rotor 36 being made in two sections firmly secured together via screw threads 50. The upstream portion of rotor 36 is provided with a plurality of equally spaced radially extending blades 52, as best seen in Fig. 7. Each of these blades spirals around a central portion or hub of the rotor by a preselected amount and, in the embodiment shown, these helical blades 52 spiral around the rotor hub in the left hand direction so that, upon flow of drilling fluid through the turbine, the rotor rotates to the right, i.e. in the clockwise direction as shown in Figs. 6 and 7. The individual rotor blades 52 are securely welded to the hub or core portion of the rotor while the outer edges of same are in closely spaced relationship to the thin walled portion of the stator 34 as clearly shown in Fig. 5.

Downstream of the rotor blades 52, both the rotor and stator are arranged to provide a rotary valve broadly designated by reference 56. With reference to Figs. 5. and 6, both the rotor and stator are shaped immediately downstream of rotor blades 52 so as to provide an open annular chamber 58 for the drilling fluid. The rotor 36 includes a valving section 60 having generally flattened side walls 62 and arcuate end walls 64. This valving section 60 rotates within a valving section 66 of the stator, such valving section 66 being arranged to cooperate closely with the valving section 60 of the rotor and, for this purpose, stator valving section 66 includes smooth surfaced cylindrical segments 68 arranged to cooperate with the arcuately contoured cylindrical segment walls 64 of the rotor section 60. Stator valving section 66 also includes oppositely disposed radially arranged fluid exit ports 70 which communicate with diametrically opposed fluid passageways 72 which extend in the axial direction to carry the drilling fluid in a downstream direction, such passageways 72 communicating with further fluid passageways 74 which converge together and communicate with a further main fluid passageway 76 which leads outwardly of the downstream end of the flow pulsing apparatus.

It should also be noted that the stator 34 is provided with a pair of diametrically opposed relatively small axially disposed fluid passageways 80 which, as best seen in Fig. 6, are unaffected by the relative angular position between rotor 36 and stator 34. In other words, these smaller passages 80 serve to pass drilling fluid through the apparatus at all times. It might be noted here that for purposes

of fine tuning the apparatus, bushings could be inserted into the passages 80 thereby to provide continuous flow passages of the exact size desired. It is furthermore noted here that since the drilling fluid may contain a certain amount of gritty contaminants that there should not be a close running fit between arcuate wall portions 64 of the rotor valving section and cylindrical segment walls 68 of the stator valving section. Rather, a small radial gap should be left between them so that such small particles will not cause undue abrasion or even, in extreme cases, tend to cause binding of the rotor and stoppage of same.

Figure 8 illustrates diagrammatically both the main ports 70 as well as the continually open ports. The main ports 70 each define effective flow passage equal to the full size of such port with each port being closed two times for each revolution of the rotor 36. With reference to the continually open ports 80, as noted above, these may be provided with bushings to provide the desired flow area. The total flow area provided by ports 80 would be as a general rule of thumb about as large as the total flow area provided by the jet nozzles in the drilling bit. Another effectively open port illustrated diagrammatically in Figure 8 is the leakage area around the main ports caused by the above-noted clearance between arcuate walls 64 of the rotor valving section and the interior cylindrical walls of the stator valving section. This leakage area is relatively small in comparison with the other flow areas referred to and is not sufficiently important as to warrant further discussion.

In the operation of the apparatus shown in Figs. 5 through 7, it will be assumed that the drill string is rotated in the usual fashion, thus effecting rotation of housing 26 and the stator 34 which is fixed thereto with rotation of the housing being ultimately transmitted to the previously noted drill bit 20. The drilling fluid or mud pumps located at the surface create a downward flow of drilling fluid through the interior of the drill string and this enters the axial bore 42 provided in the housing, such flow entering via annular region 46 into the flow passages defined between the straight stator blades 48. This flow, in the axial direction, then enters the turbine section of the rotor and, by virtue of the helical shape of the rotor blades 52, the rotor 36 is caused to rotate in the right-hand direction. As the rotor rotates, the valving section 60 of the rotor also rotates therewith thus intermittently opening and closing the fluid exit ports 70. The ports 80, as described previously, continue to pass a relatively small portion of the flow therethrough at all times. By virtue of this action, a fluctuating or pulsating flow of the fluid is allowed to pass through the valving section and outwardly through the axial passage 76 at the lower end of the flow pulsing apparatus 16.

Figure 9 is a graph illustrating the bit-jet pressure made available during operation of the apparatus described above. It will be appreciated that the pressure of the drilling fluid supplied to the apparatus is a function of several different items. One component of the pressure comprises the hydrostatic pressure which is directly proportional to the height of the column of drilling fluid

standing in the drill string. This of course varies directly in accordance with the depth of the drill bit below the surface. The second component of the applied pressure is the pressure supplied by the drilling fluid pumps on the surface, which pressure is available to push the flow of drilling fluid through the jets in the drilling bit.

With reference to Figure 9, the two components of the applied pressure namely the hydrostatic pressure and the pump pressure, are clearly illustrated. The pressure profile shown would be the pressure as measured downstream of the valving arrangement as, for example, in passageway 76. The pressure profile upstream of the valving arrangement, e.g. in port or passageway 42 would be essentially a mirror image of the pressure profile shown in Fig. 9. It will be appreciated that as the exit ports 70 are closed off by rotation of rotor valving section 60, that the momentum of the drilling fluid in the drill string creates a water hammer effect which, as is well known, means that the flow energy of the fluid is being converted into dynamic pressure energy. Thus, as ports 70 are closed, the pressure of the fluid on the upstream side of the valving arrangement increases. Then, with continued rotation of the rotor, the exit ports 70 begin to open and this high pressure appears on the downstream side of the valve. Thus as ports 70 are being opened, the pressure on the downstream side is increasing as illustrated by part D of the pressure curve. The peak pressure occurs at point E. As the valve moves to full open position this pressure is gradually dissipated and falls down to the nominal pressure F. Then, with continued rotation of the

rotor, the pressure on the downstream side of the valving arrangement drops suddenly as illustrated by section G of the pressure curve, reaching a minimum pressure at point H. At point H, representing minimum downstream pressure, it will be realized that, owing to the above-mentioned water hammer effect, the pressure on the upstream side of the valve will be at a maximum and hence as the ports 70 begin to open this pressure increase will be transmitted through the rotary valve thus resulting in a rapid pressure increase along section D, as noted previously, with the result being that peak downstream pressure E is again exhibited. This procedure repeats itself in a cyclical fashion, and, with the apparatus as illustrated in Figs 5-7, it will be appreciated that two complete pressure cycles as illustrated in Fig. 9 are achieved for each complete rotation of the rotor 36.

It will of course be appreciated that the pulsing action described above causes a pressurized pulsating flow of drilling fluid to be made availabe to the drill bit. By varying the size of the continually open passages 80 in relation to the size of the exit ports 70, the peak pressures attained can be made considerably larger than the nominal pressure. It should be possible to make the peak pressure to be double the nominal pressure or even triple the nominal pressure depending on the end use desired. It should also be noted here that the frequency of the pulsation can be varied by changing the helix angle on the rotor blades 52. The faster the rate of rotor rotation, the higher the pulsation rate. By way of example, a pulsation rate or frequency in the order of 1200 cycles/minute has been successfully used; however, it is expected that frequencies of twice this value, or even more in some cases, could be used.

It is important to realize that the pulsating pressurized flow being applied to the cleaning nozzles or jets of the drill bit provides greater turbulence and greater chip cleaning effect than was hitherto possible thus increasing the drilling rate in harder formations. In softer formations where the eroding action of the drill bit jets has a significant effect, the pulsating, high turbulence action also has a beneficial effect on drilling rate. By making use of the water hammer effect, these high peak pressures are attained without the need for applying additional pumping pressure at the surface thus meaning that standard pumping pressures can be used while at the same time achieving much higher than normal maximum flow velocities and pressures at the drill bit nozzles.

Figs. 10 through 12 show a flow pulsing apparatus very much the same in principle as that described with reference to Figures 5 through 7 and like reference numerals have been applied to like parts. The basic difference is in the valving arrangement. The rotary valving arrangement 90 involves the use of a rotor valving portion 92 having a plurality of radially outwardly extending finger-like members 94 which rotate in close cooperating relationship with a radially extending wall portion 96 of the stator 34. This wall portion 96 is provided with a plurality of axially arranged flow passages 98. As best seen in Fig. 11 these flow passages 98 are equally spaced apart in the angular direction. The rotor valving members 94 are not, however, equally spaced apart in the angular direction but, rather, are arranged so that during rotation of the rotor, at certain angular positions

of the rotor (as shown in Fig. 11) all six axial ports 98 are fully open while at the other extreme, only two of such ports 98 are fully open. The valving arrangement thus shown in Figs. 10 through 12 provides for a higher frequency of pulsation than the previously described embodiment. At the same time, the magnitude of the pressure peaks would be somewhat less than that for the previous embodiment so this arrangement as shown in Figs 10 through 12 would be best suited for applications wherein high frequency drilling is required with low pressure peaking.

In both of the embodiments described above, owing to the water hammer effect created as a result of the intermittent or fluctuating flow of fluid, mechanical vibrating forces will be applied to the flow pulsing apparatus which will tend to act in the direction of the drill string axis, which pulsing or vibrating action will be advantageously transmitted to the drill bit. This pulsating mechanical force on the drill bit complements the pulsating flow being emitted from the drill bit jet nozzles thereby to further enhance the effectiveness of the drilling operation, i.e. to increase the drilling rate.

The above-described mechnical pulsing action can be further enhanced by the use of the apparatus illustrated in Fig. 13. In Fig. 13 a form of shock tool 100 is connected via the usual tapered screw threads 102 to the lower end, i.e. the outlet end of the flow pulsing apparatus 16. The shock tool 100 includes an outer casing portion 104, within which is slidably located an elongated mandrel 106. The lower end of mandrel 106 has an internally threaded section 108 which allows the same to be connected to the drill bit 20 either directly or by way of a short sub section.

Suitable annular seals 110 and 112 are provided between the housing 104 and the upper and lower ends of the mandrel 106 thereby to assist in preventing contaminants from entering between these two components and hindering their relative axial movement. The upstream end of mandrel 106 is provided with a collar portion 114 and this provides an annular step against which the upper end of a spring stack 116 rests. The lower end of spring stack 116 rests against shoulder 105 fixed relative to housing 104. This spring stack 116 is conveniently comprised of a plurality of annular belleville-type washers although any suitable compression spring means may be provided.

It will be seen by reference to Figure 13 that the upper end of the mandrel, as well as the central passageway through the mandrel, which is filled with pressurized drilling fluid during use, in effect defines an open area piston. During operation there is of course a pressure differential between the pressure of the drilling fluid within the mandrel and the pressure of the drilling fluid which is outside of the shock tool 100 altogether namely, the drilling fluid which is returning upwardly between the tool and the wall of the well bore. By virtue of the fact that the drilling fluid leaving the flow pulsing apparatus 16 is pulsating at a predetermined frequency as noted above, this pressure differential also is varying accordingly and as this pulsating differential pressure acts on the open area piston noted above, it serves to extend the mandrel 106 relative to the housing 104 with the result being that that the shock tool 100 effectively performs as a "mud hammer". This hammering effect is of course

directly transmitted to the drill bit 20. Again, the drilling fluid leaving the jet openings 22 in drill bit 20 will be subject to the pressure fluctuations described above and will perform the desired enhanced hydraulic effect. The shock tool 100, behaving as a "mud hammer" applies a strong pulsing or vibrating action to the drill bit thus causing it to drill more effectively. At the same time, it should be realized that the peak loadings applied to the drill bit are somewhat less than in the case of a conventional mud hammer in that, owing to the hydraulic action involved, the pressure peaks are somewhat rounded or curved as illustrated in Fig. 14. These curved peaks effectively create less damage to the drill bit at higher loadings thus resulting in a longer bit life.

The use of the shock tool 100 as shown in Fig. 13, although of great importance in many formations, is not required in certain other drilling conditions ie. its use is optional. It is also important to note that the shock tool 100 can be positioned above the flow pulsing apparatus 16. The main modification needed to the shock tool 100 in this case is the replacement of the internally threaded section 108 with an externally threaded section, similar to section 32, to allow it to be connected to the internally threaded portion 30 of the flow pulsing apparatus 16. In this modified arrangement the shock tool will respond to the pressure fluctuations existing on the upstream side of the valving arrangement as described previously ie. the shock tool 100 will be under the influence of a pressure profile which is a mirror image of that shown in Fig. 9. This reverse timing effect can give rise to drilling efficiencies equal to or exceeding those of the arrangement described previously wherein

the shock tool 100 is located below pulsing apparatus 16. The alternative arrangement is indicated in Fig. 13 wherein dashed lines etc. are used to illustrate that the shock tool 100 can be located above the flow pulsing apparatus 16.

Numerous modifications and variations will become apparent to those skilled in this art in the light of this specification. Accordingly, the invention is not to be limited to the specific embodiments disclosed but is to cover all modifications and equivalents as fall within the spirit or scope of the invention.

CLAIMS

1. Apparatus for providing a pulsating flow of drilling fluid to a rotary drill bit (20) characterised in that it comprises a housing (26) adapted to be connected in a tubular drill string above the drill bit (20) and to be supplied, in use, with pressurized drilling fluid via the tubular drill string, said housing having a passageway (42) for the flow of the drilling fluid therethrough from an inlet (30) to an outlet (32) of the housing, and pressure varying means (34,36,52,56,60,70,72;90,92,94,96,98) in the housing for cyclically varying the rate of flow of drilling fluid through the housing to create a varying pressure in the drilling fluid leaving the outlet (32) from the housing (26) whereby, in use, a pressurized pulsating flow of such fluid is supplied to the drill bit (20).

2. Apparatus according to Claim 1, characterised in that the pressure varying means (34,36,52,56,60,70,72; 90,92,94,96,98) in the said housing (26) incudes a rotor (36) adapted to rotate relative to said housing (26) in response to the flow of fluid through the said housing, the rotor (36) including rotary valve means (56) cooperating with a plurality of main flow passages (70,72;98) for the drilling fluid in said housing (26) alternately to close and open such main passages (70, 72;98) to create a cyclical pressure fluctuation at the outlet (32) of said housing (26) during continuous rotation of said rotor (36).

3. Apparatus according to Claim 2, characterised in that it includes further flow passages (80) in the said housing (26) for the drilling fluid which are unaffected by and remain open during rotation of said rotary valve means (56).

4. Apparatus according to Claim 2, characterised in that the rotor (36) includes a turbine section having blades (48,52) thereon adapted to apply torque to the rotor (36) in response to the flow of the drilling fluid through the turbine section of the housing (26).

5. Apparatus according to any of Claims 2, 3 or 4, characterised in that the said main flow passages (70,72) include generally radially arranged ports (70) in the housing (26) and the rotary valve means (56) are arranged to rotate in close cooperating relation to the said ports (70) whereby alternately to open and close the ports (70) during rotation of the rotary valve means (56).

6. Apparatus according to Claim 2 or Claim 4 characterised in that the main flow passages (70,72;98) include generally axially arranged flow passages (98) and the said rotary valve means (56) comprise a section of said rotor (36) having radially arranged portions (94) which move in close proximity to entrance portions of said axially arranged flow passages (98) whereby alternately to open and close these during rotation of said rotor (36).

7. Apparatus for providing a pulsating flow of drilling fluid to a rotary drill bit (20) characterised in that it comprises a housing (26) adapted to be located in a tubular drill string above the drill bit (20) and having a passageway (42) for the flow of drilling fluid therethrough from an inlet (30) to an outlet (32) of said housing (26); stator means (34) in the said housing (26) for directing the flow of drilling fluid in a preselected path; rotor means (36) in the said housing (26) for receiving the flow of drilling fluid from the said stator means (24) and so constructed and arranged that the flow of drilling fluid therepast effects rotation thereof relative to the said housing (26); said rotor means (36) including flow altering means (56) adapted to create a pulsating variation in the flow of the fluid leaving the outlet (32) of the said housing (26) in response to the rotation of said rotor means (36).

8. Apparatus according to Claim 7, characterised in that the said housing (26) has main fluid flow passages (98) therein with the said flow altering means (90) arranged to open and close at least certain of said main flow passages (98) during rotation of the rotor (36) to provide the pulsating flow variation.

9. Drilling equipment comprising apparatus according to any preceding Claim and including a drill string connected to the inlet (30) of the said housing (26) to supply pressurized drilling fluid thereto, and a drill bit (20) having jet openings for the drilling fluid connected downstream of the outlet (32) of said housing (26) such that, during use, the cyclical

variation in the flow passing through said housing creates a water hammer effect in the drilling fluid thus resulting in high pressure peaks in the fluid being supplied to the jet opening of the drill bit (20) and a pulsating mechanical force on the drill bit (20).

10. Drilling equipment comprising the apparatus according to any of Claims 1 to 8, in combination with a drill bit (20) having jet openings for the drilling fluid, and a shock tool (100) connected in alignment with the said drill bit (20) and drill string, the said shock tool (100) including a pair of relatively movable members (104,106) arranged to respond to the cyclical variation in the flow of drilling fluid and pulsating pressure variation created thereby by imparting a longitudinal vibrating action to said drill bit (20) during the course of rotary drilling while at the same time a pulsating flow of the drilling fluid is emitted from said jet openings.

11. Drilling equipment according to Claim 9, wherein said drill bit (20) has jet nozzles thereon for directing the pulsating drilling fluid and clearing cuttings from the bottom of the bore hole.

12. Drilling equipment according to Claim 9 or Claim 11, further including means (100) responsive to the variations in the flow of drilling fluid and the pressure changes associated therewith and connected in said drilling string to apply longitudinal pulsating forces to said drill bit (20) for vibrating the latter during drilling.

13. Drilling equipment including a rotatable hollow drill string adapted to carry pressurized drilling mud downwardly into a well bore, and a drill bit (20) connected to the lower end of the drill string, characterised in that there are provided means (16) in the said drill string above the said drill bit (20) adapted to be activated by the flow of drilling mud whereby periodically to interrupt a portion of the flow of drilling mud so as to set up a water hammer effect therein so that pulsating forces are applied to the drill bit (20) which is supplied with a flow of the drilling mud at a pulsating pressure, the said drill bit (20) having nozzle means thereon to direct the pulsating pressure flow to regions of the bottom end of the well bore during use to clear away cuttings produced by the drill bit (20).

14. Drilling equipment according to Claim 14, characterised in that the said means (16) in the drill string is adapted so as periodically to interrupt a major part of the flow of drilling mud while the remaining minor part of the flow is uninterrupted.

15. Drilling equipment according to Claim 14, characterised in that the said means (16) in the drill string comprises a rotary hydraulic motor (52) adapted to be driven by the flow of drilling mud in the drill string and having rotary valve means (56) associated therewith for periodically interrupting the major part of the flow of drilling mud to provide the said pulsating flow to said drill bit (20).

16. Drilling equipment according to Claim 13, 14 or 15, characterised in that the said means (16) in the drill string is located adjacent the lower end of such drill string to enhance the water hammer effect by virtue of the length and mass of the column of mud contained in the said drill string.

17. Drilling equipment according to claim 13, 14,15 or 16 characterised in that it further includes a tool (100) interconnected in and aligned with the said drill string and located adjacent said means (16) to periodically interrupt the flow of drilling mud and said drill bit (207), the tool (100), including a pair of relatively movable members (104,106) arranged to receive and to respond to the pulsating pressure of the drilling mud by relative axial displacement whereby to impart a longitudinally vibrating action to said drill bit (20) while at the samd time a pulsating flow of the drilling mud is emitted from the nozzle means of the drill bit (20).

18. A method of drilling a bore hole including rotating within a bore hole a hollow drill string to the lower end of which a drill bit (20) is connected, such drill bit having nozzle means therein for directing drilling mud supplied thereto via said drill string to the bottom of the bore hole to clear away cuttings produced by said bit and/or to assist in the cutting of softer formations, characterised in that a portion of the flow of drilling mud through said drill string is interrupted in a cyclical fashion so that said drill bit (20)

is supplied with a pulsating pressurized flow of the drilling mud.

19. The method of claim 18 characterised in that the interruption of the flow of drilling mud is effected adjacent the lower end of the drill string whereby inertia effects arising from the interruption of the flow cause pulsating forces to be applied to said drill bit (20) and create pressure peaks in the flow passing into the drill bit (20) so that a pulsing flow is emitted from the nozzle means thereof.

20. The method of Claim 19, characterised in that it further includes providing means (100) adjacent said drill bit (20) for vibrating same lengthwise of the drill string in response to the pulsating pressure of the drilling mud.

21. The method according to Claim 18, 19 or 20, characterised in that the cyclical interruption of the flow of drilling mud is effected by passing the said mud through a vaned rotor assembly (36,52) to rotate the same, the rotor assembly having rotary valve means (56) associated therewith to effect the said cyclical interruption in the said flow.

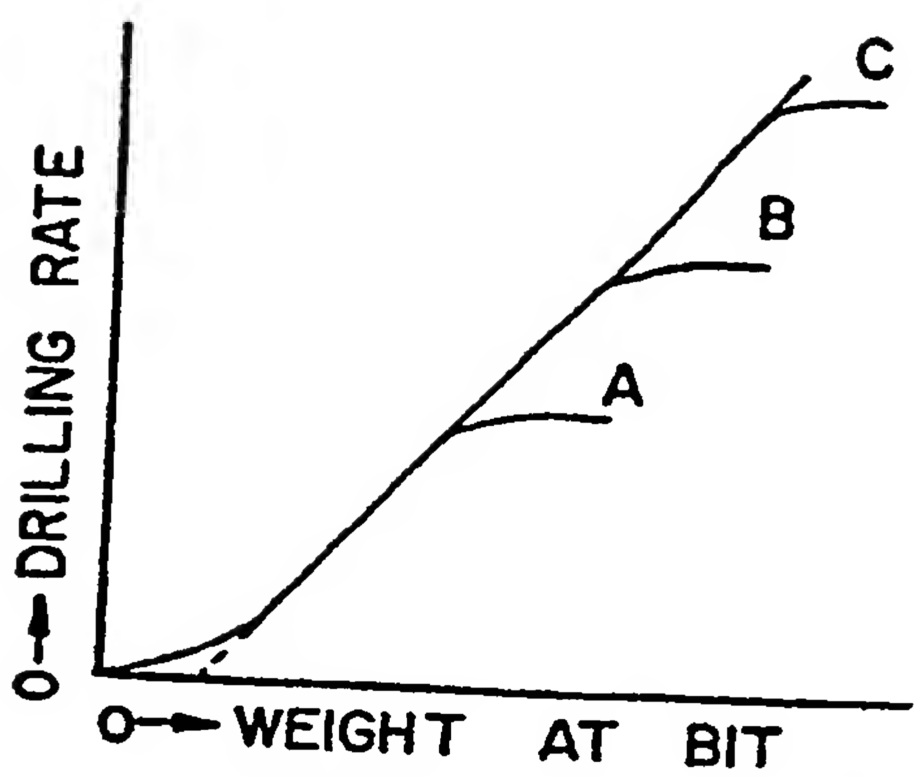

FIG. 1

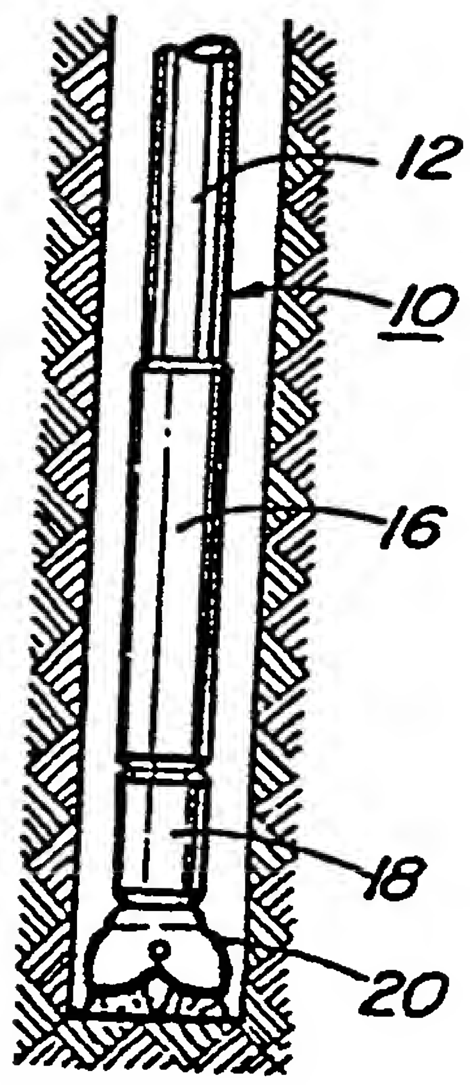

FIG. 2

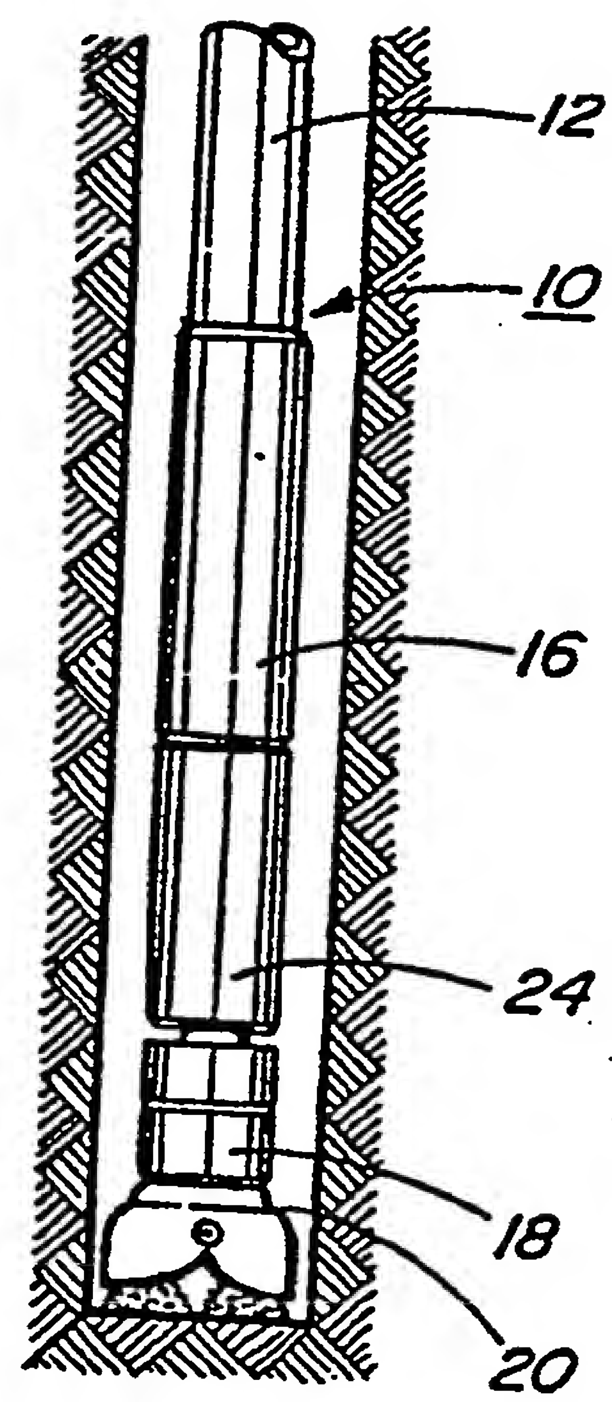

FIG. 3

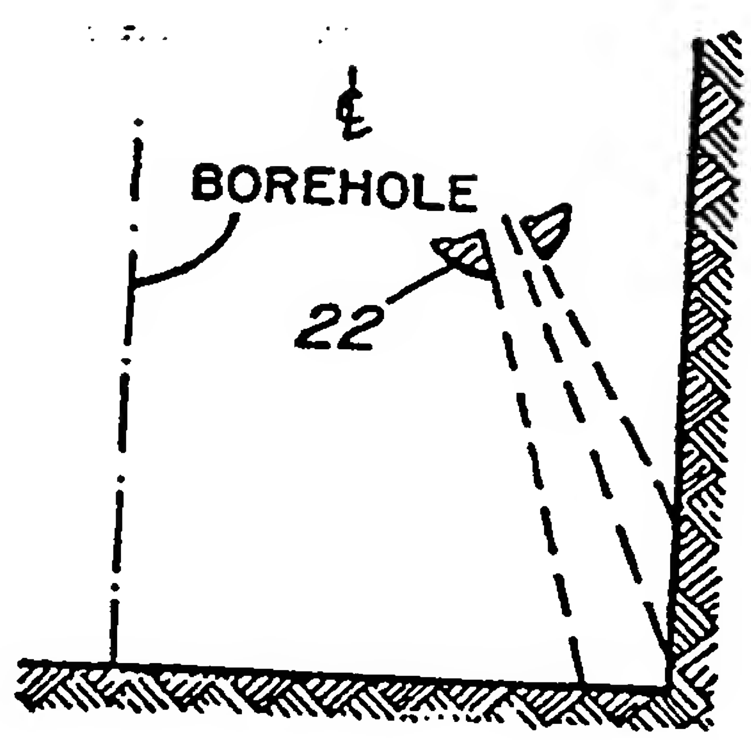

FIG. 4

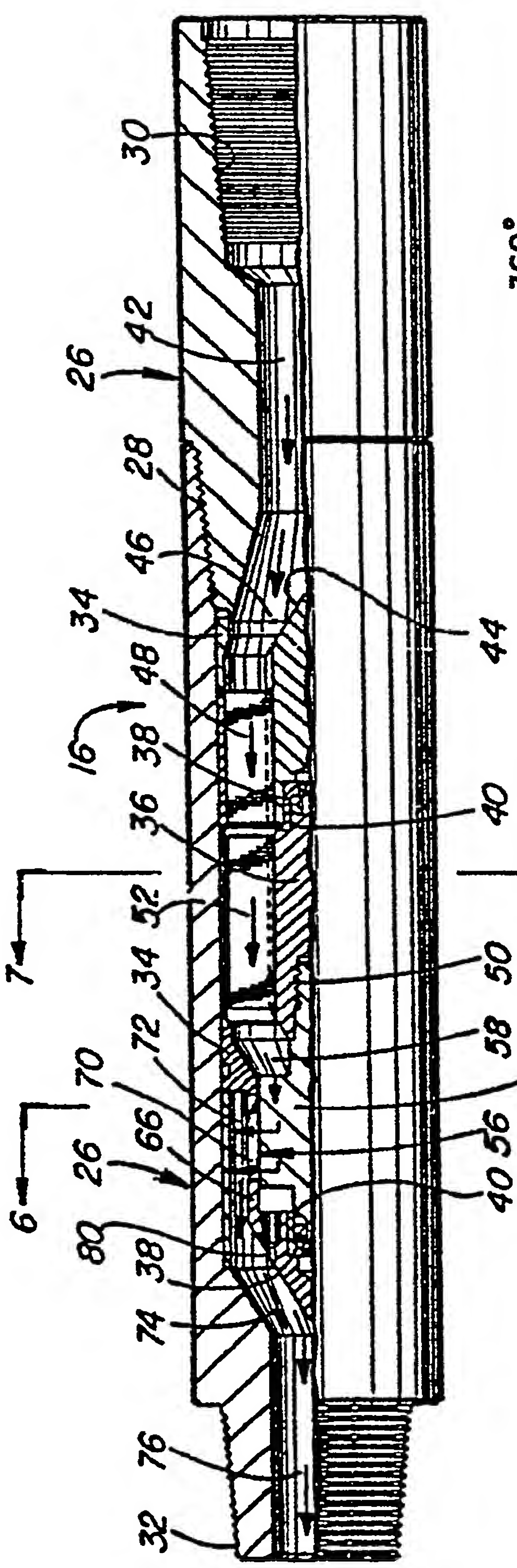

FIG. 5

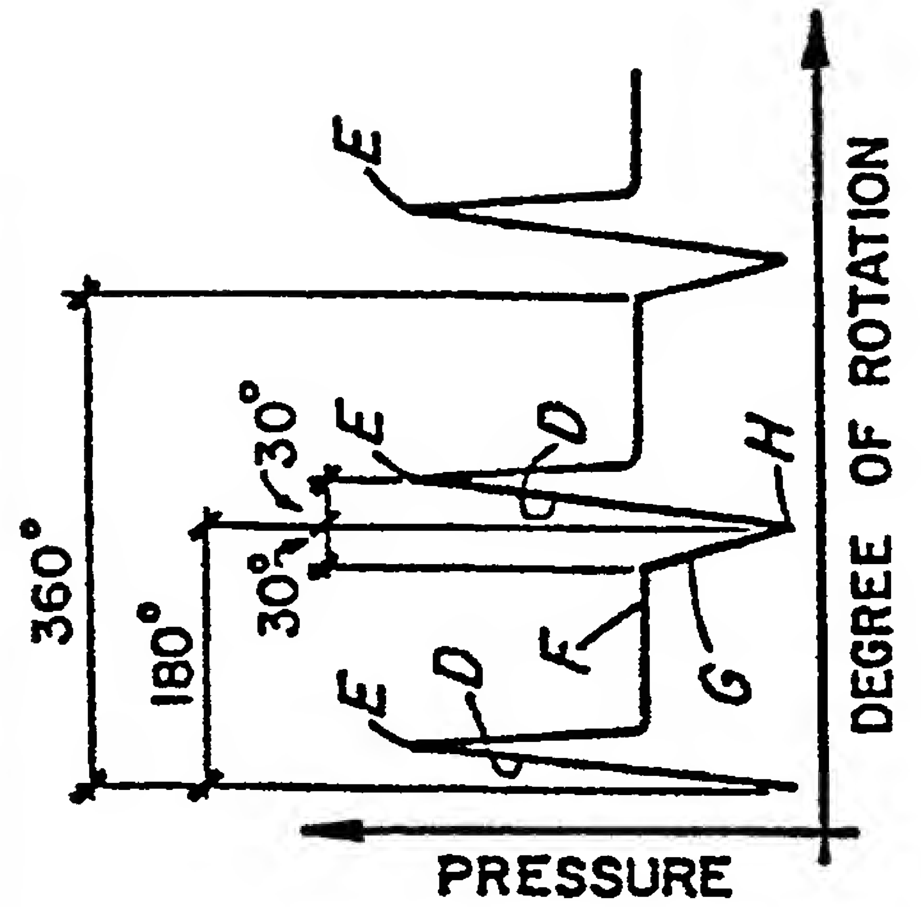

FIG. 9

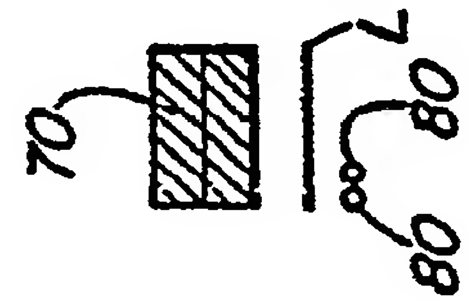

FIG. 8

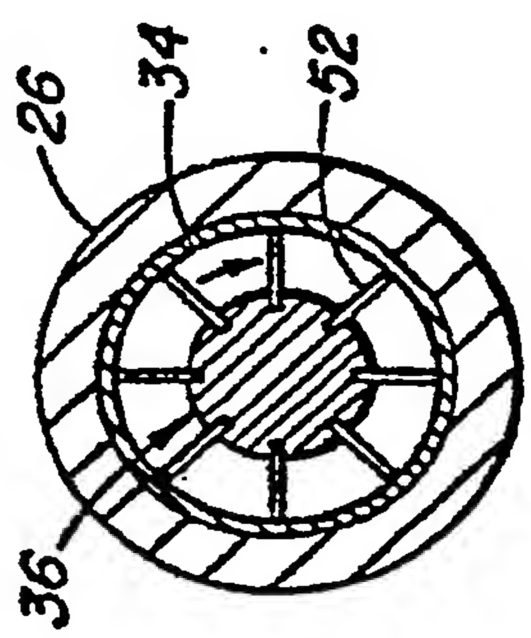

FIG. 7

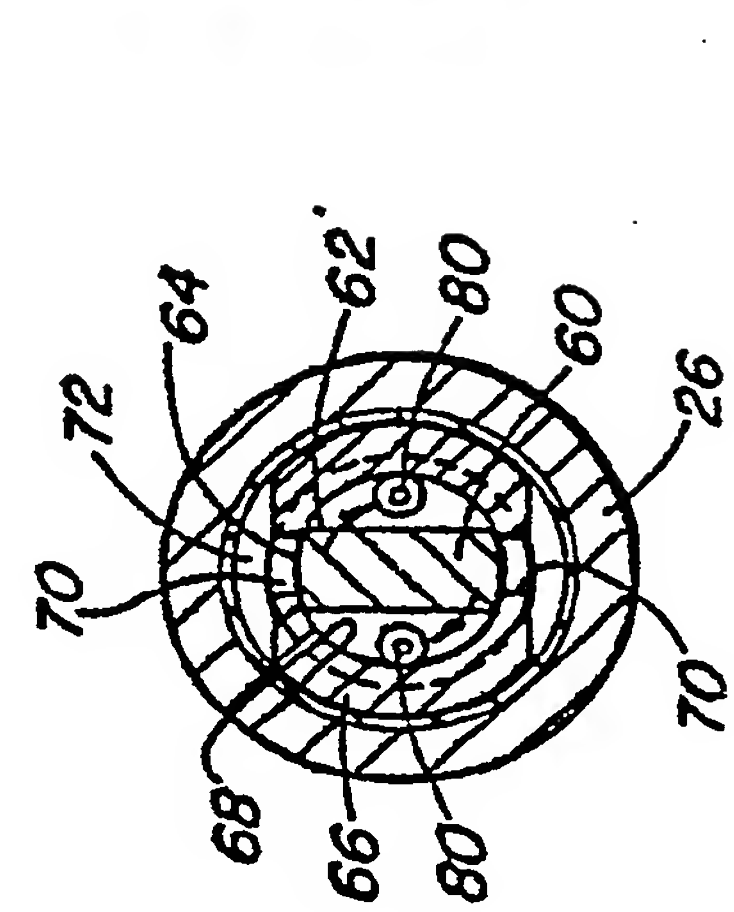

FIG. 6

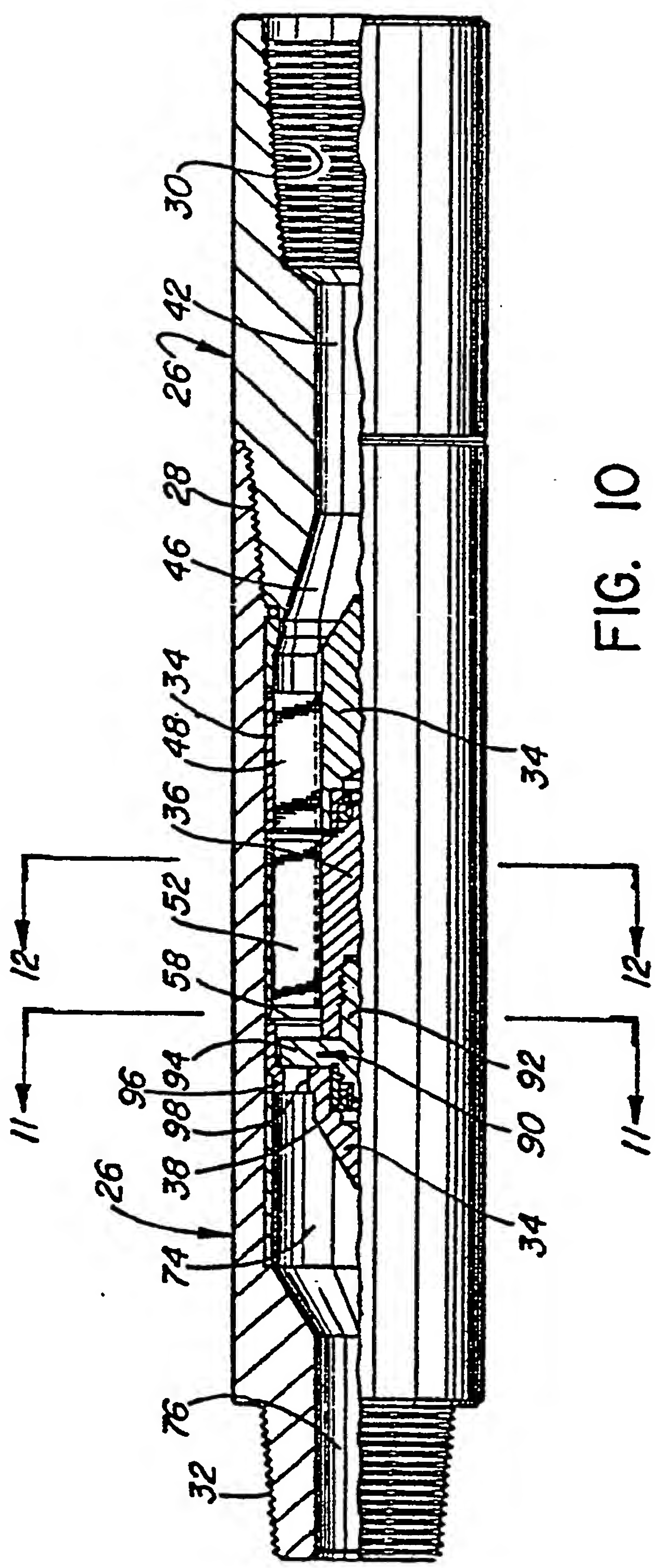

FIG. 10

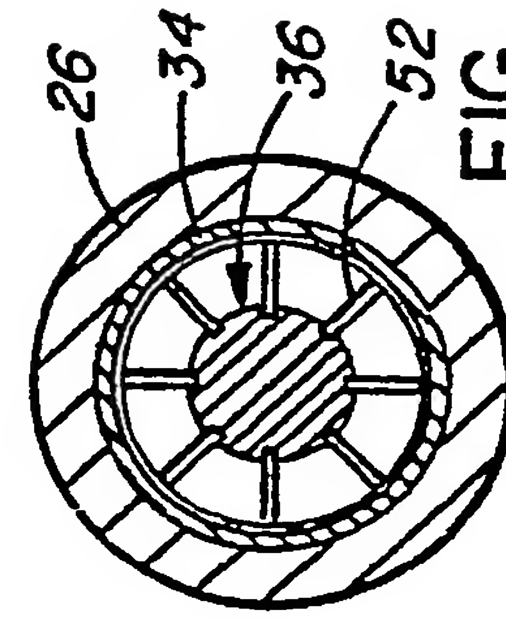

FIG. 12

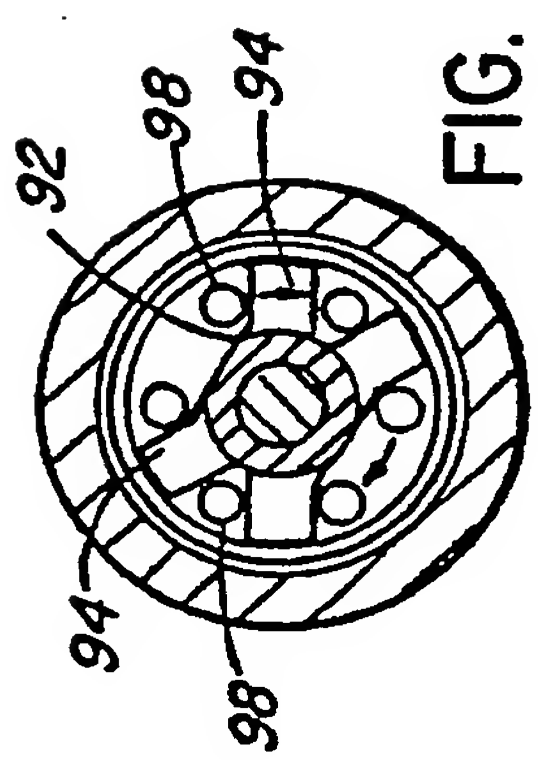

FIG. 11

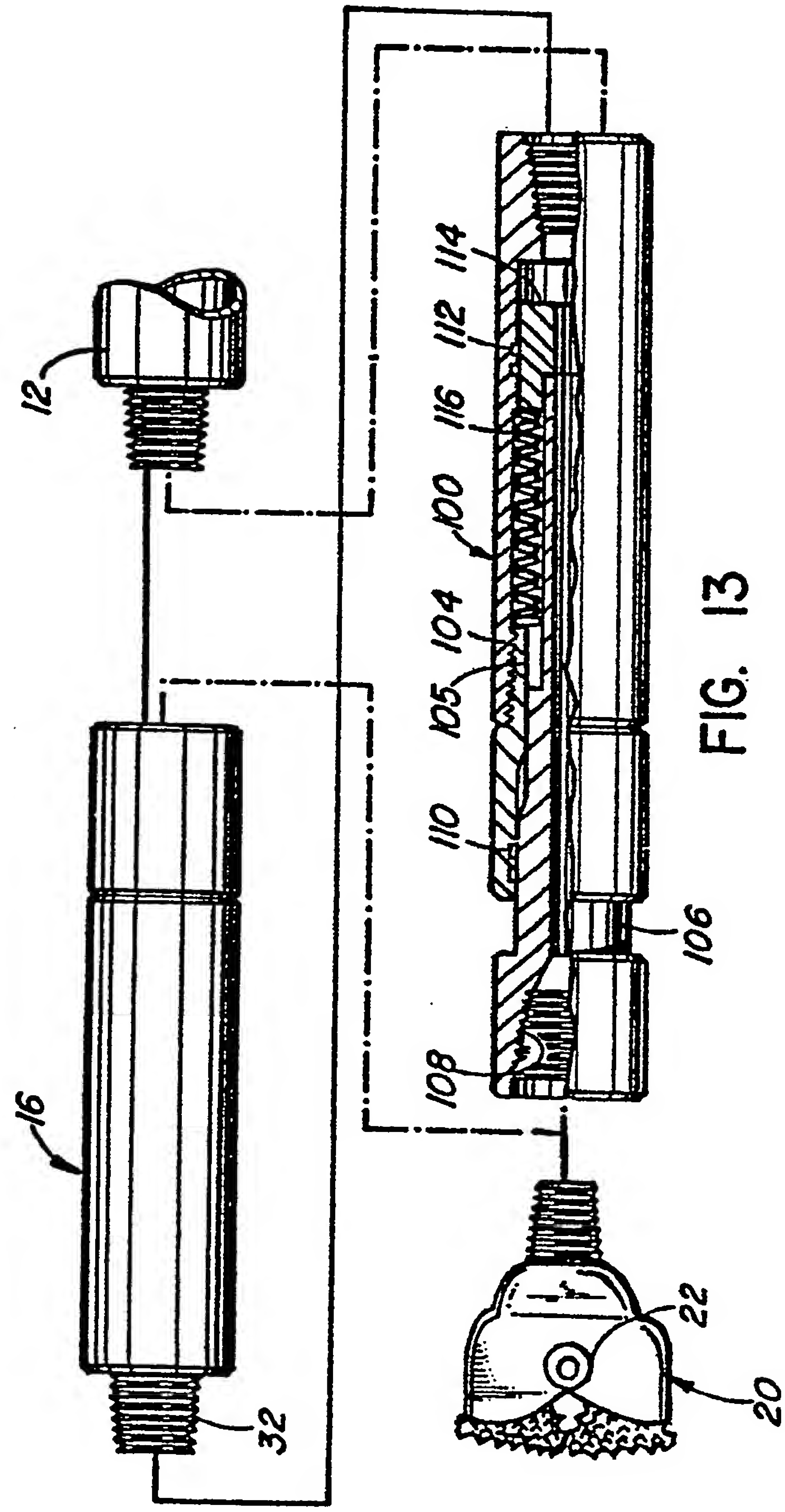

FIG. 13

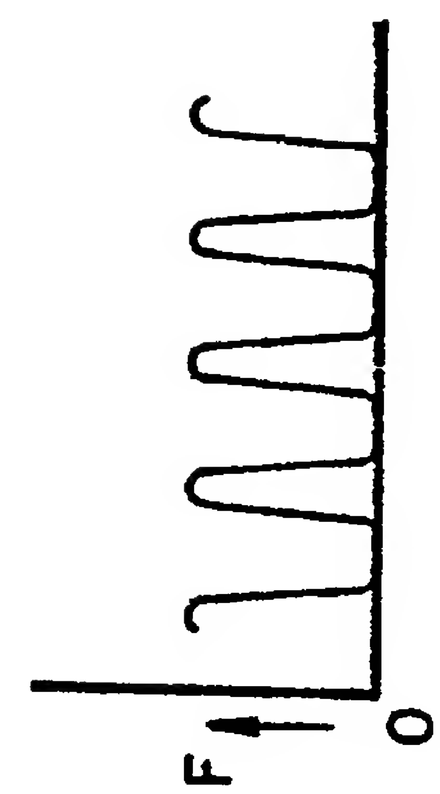

FIG. 14